THE IMPORTANCE OF RESEARCH AS A MEANS OF INCREASING AGRICULTURAL PRODUCTION

By M. B. Waite,

Pathologist in Charge, Fruit Disease Investigations, United States Department of Agriculture.

The great new feature of the modern progress in agriculture is the rapid increase in the utilization of science and the results of scientific research as a source of information and guidance in improving and perfecting agricultural methods.

Research in agriculture may be divided into two main classes: strictly agricultural research, and scientific research. The first type is concerned primarily with actual methods of growing and utilizing crop plants with animal production, etc. It takes agricultural methods developed empirically and subjects them to critical experimentation. It gathers the methods developed in various parts of the world and tests them out experimentally, under given conditions. It utilizes precepts developed in the sciences, or rather, tests their availability for use in actual practice, by trying them out in the field. It could, however, theoretically, be carried on in part without any help from science. As a matter of fact, at the present time it is becoming more and more influenced by scientific data. All such questions as depth and kind of tillage, varieties of crops to be planted in different localities, kinds of animals to use for certain purposes, depth and distance and time of seeding and planting, varieties suited for different sections and different purposes, rotation of crops, kinds and amounts of fertilizers to use, time and amount of water, when this is artifically applied, and, in fact, the development of all the various routine practices of actual farming come within its scope.

The second type is research in the sciences which have a direct bearing on and are helpful to the development of agriculture and agricultural methods. These sciences are principally chemistry, including physiological chemistry; physics, including soil physics; zoölogy in nearly all its branches, including entomology, animal

physiology and animal pathology; botany in most all its branches, including plant physiology, plant pathology and bacteriology.

Agriculture is so broad in its scope and requirements that it utilizes, in varying degree, and gets help from, nearly all the other arts as well as from the sciences. For example, modern agriculture utilizes, to a very large extent, engineering, architecture, manufacturing and transportation among the useful arts. It also utilizes mathematics, astronomy, meteorology, geography and geology among the sciences in addition to those mentioned above.

It has been observed, by many, that farmers, as a class, are conservative—that they hesitate to take up new ideas. This is a natural result of the old-time empirical method. The farmer was compelled to stick to the time-tried methods known to be successful by long experience. Any other course than this was to invite disaster.

Referring, again, to the strictly agricultural research work, no one can accuse the present investigators in this line of being conservative. They are hunting for something new all the time. In fact, they may even be accused, at times, of being too anxious for novelties in methods and of not giving the proper weight to the best empirically developed procedures. These investigators have, at the present time, three possible sources of information in perfecting agricultural routine processes: first, the old line empirical methods; second, the results of tests with growing crops under modern experimental conditions; and third, the data and results available from the different sciences.

We are now ready to answer the question as to why science has only recently come to the aid of agriculture, particularly why chemistry and the biological sciences have been of so little use to the farmer. It seems to me the real reason is very simple. It is because our knowledge of the sciences has been so imperfect and incomplete. No one knows better than the investigating scientist the fragmentary and incomplete nature of our exact knowledge. This is particularly true of the biological sciences. Take botany, for instance; here is a science which deals with plants and with plant life in all its various phases. Why has the science of plants, until recently, been of so little use to the cultivator of plants, and why has this science lately been utilized in so many different ways with such splendid results? It is because the science itself was weak. Only

fragmentary, isolated facts here and there had been worked out; only a few of its principles had been discovered.

Bacteria had been known and described to some extent since the days of Ehrenberg (1830). It remained for Pasteur, in 1862, to prove that they were the real cause and not the result of fermentation. He discovered the first bacterial disease, a silk-worm disease, in 1870. A year or two later, he proved that anthrax of cattle was caused by a bacillus. Burrill, in 1878, discovered that pear blight was caused by bacteria, the first discovery of a bacterial plant disease. Koch discovered the germ of tuberculosis in 1884. Since that time there has been a continual stream of new and important discoveries in bacteriology of immediate and practical benefit to agriculture.

The fungus diseases of plants have been known and described for one hundred and fifty years. The number has been added to continually until it runs up into the thousands. Many single species of both cultivated and native plants have from fifty to one hundred fungus enemies attacking them. Not until Millardet discovered the efficacy of Bordeaux mixture in the control of the vine mildew in 1883 and published his results in 1885 did we have a satisfactory and direct way of killing these fungus enemies or preventing their attacks on the host plant. A new word, "fungicide," had to be added to the dictionary.

One of the effects of the utilization of the various sciences in agriculture has been to bring to notice the gaps in the sciences. The demands of agriculture, therefore, for new knowledge in science have acted as a powerful stimulus to scientific men to take up many problems which might otherwise pass unnoticed. In this way agriculture has greatly stimulated certain lines of research, such as many problems in chemistry, including physiological chemistry, and many branches of botanical and zoölogical science, particularly in pathological and bacteriological lines. Agriculture, therefore, has not only drawn heavily on scientific results, but has in turn enormously stimulated intellectual activity in these lines. In a much more direct way, however, it has fostered and encouraged scientific research by financing and supporting it. It is safe to say that there is far more scientific work being done during the current year in botany financed by agricultural appropriation bills than all the other research botanical activity combined, whether amateur

or professional. What we need is more real science. That, I think, soon becomes apparent to all engaged in attacking problems of agricultural production.

Chemistry has done great things for agriculture. It has furnished the methods of fertilizing the soil and of securing these fertilizers from the earth,—potash, phosphoric acid, and nitrogen. It has helped us in compounding a balanced complete fertilizer, varying to suit soil conditions and crops. It taught us how to feed a balanced ration to our stock. It provided simple tests by which the farmer can determine the amount of butter fat in any given sample of milk and thus furnished a guide for distinguishing between productive and unproductive animals. Chemistry, combined with plant-breeding methods, has increased the sugar content of sugar beets by furnishing a method for determining the high sugar content of certain specimens to be used for seed production. It furnishes the basis of much agricultural experimentation and assists in nearly all lines of research.

The science of zoölogy has contributed much information of use to agriculture. Perhaps in no way has it been more useful than through the researches on the diseases of domestic animals and the methods of controlling or mitigating these diseases. Many of these diseases are not only contagious to the animals, but are doubly serious because communicable to man. Zoölogical science has furnished the basis for the elaborate system of meat inspection, of dairy inspection, and of quarantine operations. The introduction of the tuberculin test in eliminating tuberculosis from dairy herds may be cited as a fine piece of work. In some animal diseases, such as the foot and mouth disease and swine plague, we are still in the condition of not enough science. In neither of these contagious diseases has the germ or the real cause of contagion been discovered. Mendel's law and the principles of animal breeding worked out scientifically have given an entirely new status to this art. Results can be figured out scientifically by mathematical and biological rules and a prediction made beforehand as to what may be expected from certain crosses.

The science of entomology has been of the utmost utility to farmers in crop production in recent years. Economic entomology may be said to date back for at least two generations. The control of insect pests is perhaps one of the greatest contributions of science

to the farmer. A few striking examples may be used to illustrate the success that has been achieved in this line.

About forty years ago the potato bug or Colorado potato beetle started in to simply eat up or clean up the potato crop of this country. The entomologists readily fixed up a poison to kill him. Paris green, either sprayed or dusted on the potato plants, quickly and effectively solved the problem. The codling moth or apple worm was thought by many to originate spontaneously within the fruit. The entomologists have taught us that it is the larva of a harmless-looking little gray moth. They have worked out the life history of the insect and have given us a spraying routine with arsenical poisons by which practically complete control is maintained. The commercial apple orchardist who follows the rules laid down by the entomologists can now estimate his crop with reasonable certainty as far as this pest is concerned, as soon as the fruit has set in May. The apple buyer can know that he will get reasonably sound fruit throughout the barrel from a sprayed orchard. The good housewife can serve baked apples to her family or guests without the danger of a disgusting and nauseating worm being found when the apples are opened. One can now eat raw apples in the dark. It is safe to say that without a remedy for this one pest alone, commercial apple culture in this country could not possibly exist in anything like its present proportions. Our 86,000,000 barrels of apples in the crop of 1914 could never have been produced or marketed. With this pest controlled, apples are not only shipped to all parts of the country from the apple producing centers, but are sent all over the world. The Hessian fly has been known to destroy half to two-thirds of the wheat crop in the wheat-growing districts. The problem was attacked by the entomologists and the life history of this insect fully worked out, with the result that a practical, satisfactory remedy was developed, the utilization of which entails no additional expense to the farmer. The remedy consists merely in deferring the planting of the wheat until after the emergence and death of the adult flies. The cotton boll-weevil entered this country from Mexico about twelve years ago and its effects were so severe that it threatened the destruction of the entire cotton industry of the United States. Scientific entomologists attacked the problem vigorously and by means of a thorough investigation of the life history and habits of this pest found a way of getting around

it. In the course of this work it was learned that the critical period in the life history of the weevil occurs during the winter. It is very rare that more than three per cent of the weevils in the field in the fall survive to attack the crop the following year. The first step is to greatly reduce this three per cent by the destruction of the remains of the cotton plants in the fall after the crop is harvested. The advantage obtained by this means is followed up by procuring an early type of cotton, planting early, and pushing it to early maturity during the following season. By this means, production has been maintained from 50 per cent under unfavorable conditions to nearly or quite a full crop under favorable conditions.

The science of botany is being utilized in so many different ways in the establishment of new methods in agriculture that to attempt to enumerate even the different lines would not be within the scope of this article. Without minimizing the important results that are being secured through the new methods of plant breeding, including the application of Mendel's law and of other methods of crossing plants based on scientific knowledge, and without attempting to include the many helpful discoveries in plant physiology, it may again be pointed out, as in case of zoölogy, that some of the most marked triumphs have been secured in the control of plant diseases, particularly in case of the fungus and bacterial diseases.

Previous to 1885, the farmer, fruit grower, or gardener was practically at the mercy of the fungus pests on his crops. The losses are still very large. It has been estimated that all plant production in this country is annually reduced from 20 per cent to 25 per cent through plant diseases, and there is considerable foundation for this estimate. When we realize that we are dealing with a crop worth annually between six and seven billion dollars on the farm, the magnitude of this loss is appalling. Only a part of this can, of course, ever be reached and prevented. Many diseases are physiological, produced by the effect of climatic and soil conditions difficult or impossible to change. In the irrigated regions of the West, new types of physiological diseases have caused serious troubles in the orchards of deciduous fruits and in the orange groves. It may take years of careful research to even find out the cause of some of these troubles, and they appear to be difficult to remedy even when the cause is thoroughly known.

On the other hand, the fungus diseases of plants have yielded to research during the last thirty years in a manner that is really marvelous. The black rot of the grape, a native disease on American wild grapevines, attacked our rapidly increasing grape industry in the Eastern United States in the early '80's. The discovery of Bordeaux mixture in France by Millardet, which shows the international character and value of research, opened up new possibilities. The department of agriculture at Washington started experiments in 1886 and within the next four or five years gave to the grape growers a complete and successful routine treatment by spraying through which from 95 per cent to 98 per cent of the crop could be saved. This treatment is the very basis of the grape industry. Without it the vines would bear only ragged and unsightly bunches scarcely fit for shipping to market. The solid, well-filled bunches of smooth, bright berries of our American grapes which are shipped by the thousands of carloads annually can be claimed by plant pathology as one of its triumphs.

In much the same way, by investigating the life history of the fungus parasite, finding out its time and method of infection, and by testing with spraying mixtures, most of the fungus diseases of the apple, pear and peach have been brought under control. Apple scab, bitter-rot, black-rot and leaf-spot, pear scab, fruit spot and leaf-blight are entirely under control by routine spraying methods. The peach, with its serious disease known as brown rot, and the scarcely less serious black spot or scab, for a long time puzzled the plant pathologist, not because the character of the disease was mysterious, but because the available copper and sulphur fungicides were too injurious to the foliage. The problem was completely solved, however, by the discovery of the self-boiled lime-sulphur, which can be sprayed on to the peach without injury and which kills and prevents the fungi. By combining this, as in most spray treatments, with an arsenical insecticide, such as arsenate of lead, a complete spraying routine for the insect pests and fungus diseases of this fine fruit is now available. This benefits not only the peach grower, but every one interested in the peach business and the consumer as well. The sprayed trees yield a far better and more reliable crop, of higher grade, more perfect fruit, to the peach grower. The peaches handle and ship better in the refrigerator cars and are more satisfactory for the wholesaler and jobber. The retailer finds

that the sprayed peaches stand up and keep in condition for a longer time while he is selling them, instead or rotting on his hands and proving a disappointment, and the consumer ultimately gets more luscious peaches to eat.

Production of potatoes, cantaloupes, celery, and even tomatoes has been greatly helped through spraying methods devised against the fungus pests of these vegetable crops, and through other methods of control worked out through scientific research.

There is a family of parasitic fungi that attacks many species of plants, producing dark, powdery masses of spores in such abundance that they are called the smuts. The various species of this family attack a great variety of plants, but several species attack our great cereal crops. They produce a smut of Indian corn and the cereal smuts. One botanist has estimated that the annual losses from the corn and cereal smuts in this country exceed, in amount, all the taxes that are collected, both state and national. For most of these smuts the science of plant pathology has furnished a complete and satisfactory routine treatment, which is applied at a very small cost. It consists in disinfecting the seeds. In most cases it consists in sprinkling a little formaldehyde water over the seeds and covering them with sacks for a few hours. In one case, not controllable by chemical disinfection, namely, the loose smut of wheat, the remedy consists in dipping the seed for thirty minutes in hot water at 130 degrees F., hot enough to kill the fungus but not to kill the seed. A somewhat similar method, namely, dipping in formaldehyde water, has been found to be the remedy for potato scab and for a number of other potato diseases.

The control of plant diseases, however, is by no means limited to spraying with fungicides or to disinfecting the seeds, tubers, cuttings, etc., by chemicals and otherwise. Many diseases are controlled only by eradication methods. In case of the contagious peach yellows, the entire tree has to be pulled up, as soon as it is stricken, for the benefit of the rest of the orchard, and the community. In case of pear blight and apple cankers a thorough local eradication of the diseased spot is necessary, but not the destruction of the rest of the tree. In this disease, which is bacterial in its nature, the most important feature of the control method consists in finding and eradicating the cases of hold-over blight, where the germs live over winter to attack the trees the following spring.

In 1905, pear blight threatened to destroy the entire California pear industry. During the five years preceding it had destroyed about one-third of all the pear plantings in the state. The application of these methods, with, however, only a moderate degree of thoroughness, resulted in saving the greater part of the industry from destruction. California still ships her canned Bartlett pears all over the world.

Many of our worst and most destructive plant diseases have been imported from the old world. Some, like the chestnut bark disease and the citrus canker, are very recent importations. Plant pathologists have discussed, for several years, the advantages of supervision over plant importations. Formerly we have had no law by which plant diseases could be excluded from entry. After some conspicuous cases of recent occurrence, Congress passed the federal quarantine act. This provides for a board of scientists, known as the federal quarantine board, and gives the secretary of agriculture very wide authority in excluding, not only plant pests, but the importation of any plants or seeds, etc., which may be considered dangerous. We are now trying to shut out, from this country, several potato diseases from Europe. We are endeavoring to prevent further entrance of citrus diseases, by excluding the importation of citrus nursery stock. We are trying to keep out further importations of the European white-pine blister rust which threatens our white-pine forests with destruction. Whatever good may come from this work goes back primarily to scientific research on plant diseases.

In discussing the triumphs of plant pathology I ought not overlook some of the difficulties and failures. Quite a number of bacterial diseases of plants have been discovered, but in only a few cases are the remedies or methods of control well worked out or entirely satisfactory. The root diseases of plants are either little known, or, if known, little has been accomplished in the way of their practical control. In many of these difficult problems in plant pathology, investigators have turned to a different method of attack, namely, the breeding and selection of resistant varieties. In some cases, as in the cotton wilt of our southern states, signal success has been obtained. I should not, however, convey the idea that all plant diseases have been brought under control. Many problems, like the crown gall of fruit and other trees, the root rots,

the new citrus canker, the chestnut bark disease, and numerous others, still attack vegetation unchecked, or only partly controlled, or, in case of the citrus canker, controlled by heroic methods, such as burning up the entire tree when only a single leaf is affected.

I have mentioned earlier in this paper chemical investigations of the soil. At first, that was thought to be the important problem in soil studies. Later it was shown that the physical properties of the soil were as important, or possibly more important, than its chemical composition. Still later, within the last twenty years, it has been realized by investigators that the biological properties of the soil are even more important than either its chemical or its physical properties. The soil under our feet is teeming with bacteria, with fungi, with algae and with microscopic animal life, chiefly nematodes. The species of the latter alone run up into the thousands. This branch of science has only been entered upon. It may be scarcely said to have been exploited at all. It is no exaggeration to say that a cubic foot of ordinary garden soil presents more unsolved problems in biology than the entire solved problems up to the present time and these problems are more difficult than the building of the Panama Canal, including both its engineering and biological achievements—more difficult than wireless telegraphy, than submarine or aerial navigation, for these latter have in part been solved. If we may judge the future from the past, while great things may be expected from soil bacteriology and soil biology during the next hundred years, at the end of that period new problems just as important will be clamoring for solution. One strikingly important thing has already been brought out in soil bacteriology. In this case the discoveries are partly linked with plant physiological discoveries. I refer to the nitrogen assimilating organisms in the root tubercles of the leguminosae. It has been known for over a hundred years that clovers and some similarly related plants possess a remarkable power in renewing soil fertility when these plants are plowed under for the growing of subsequent crops. It was finally discovered that this property depended on the presence of minute tubers or tubercles that occur abundantly on the roots and that the real function was performed by a tiny bacillus which lives in these tubercles. The clover plant easily furnishes the sugar as the necessary food for the bacteria. The bacteria living in the tubercles are able to force the free nitrogen of the air into

chemical combination and build up nitrates subsequently readily converted into proteids, the most valuable food of both plants and animals.

Still later investigations have developed practical methods of artificially cultivating and distributing these germs for soil inoculation. A field which had never grown alfalfa cannot ordinarily be successfully planted to this crop. When soil is supplied with the proper strain of the root tubercle bacillus, alfalfa can be at once successfully grown. In actual practice the germs from liquid cultures are mixed with a little partly dried soil and this is sown over the surface and immediately harrowed in. In some cases the alfalfa, or other leguminous seeds, may be coated with the culture. In introducing a new leguminous crop, like alfalfa in most sections of the eastern states, soy beans from Japan, hairy vetch and other special crops of the pea, bean and clover family, this process gives us at once command of the situation. It explains the cause of many failures in the past.

The results of the new discoveries and the continual introduction of new methods have been to place agricultural experimentation on a much higher plane. It has become more and more necessary for the worker engaged in strictly agricultural research to have at least sufficient knowledge of the sciences to draw into his service all their available data. Agricultural research is giving more and more opportunity for the use of the highest brains and intellect. More than this, the farmer, himself, instead of leading a life of drudgery or carrying out a few simple routine processes, finds himself engaged in an intellectual occupation. This is particularly true of fruit and truck farming and the growing of special crops but the principle pervades all farming. We hear much these days about the agricultural uplift that is now going on, and the various influences that are bringing it about. I feel sure that a careful analysis will show that the biggest single factor which is producing this uplift, and the greatest hope for the future of this movement, is the application of science to the problems of crop production.